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KNOTTY LUMBER FOR BOXES

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INTRODUCTION

The use of wood for shipping containers has a far-reaching effect upon public interests. It affects not only the manufacturing costs in the container industry and the price that the public pays for the protection of its goods in transit, but also the degree to which the growing of timber can be made a national enterprise that is commercially attractive and a source of revenue from lands unsuited for other purposes. Shipping containers constitute one of the principal outlets for the large proportion of low-grade lumber that necessarily develops incident to the manufacture of higher grades. The utilization of this low-grade lumber is one of the key problems in the practice of forestry. Unless the lower grades can be made to stand some share of the costs of timber production, the growing of timber can hardly be made to pay its way. As this type of material can be segregated and used according to its special properties, larger amounts will be absorbed in industry, and its economic value will become stabilized and strengthened.

Practice in the use of knotty lumber in box manufacture has varied between wide limits. A large proportion of box shooks are of comparatively short lengths, and some manufacturers, believing that very few if any knots should appear in finished boxes, have used

[1] Maintained by the Forest Service, United States Department of Agriculture, at Madison, Wis., in cooperation with the University of Wisconsin.

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only practically clear boards cut from between knots or other defects. Others have gone to the opposite extreme and have cut shooks of the desired lengths without regard to size or position of knots.

Experience, observation, and tests have demonstrated that the indiscriminate use of knotty stock may produce very inferior boxes, but the elimination of all knots is unnecessary.

Information to show to what extent knots may be admitted in box parts without serious detriment to the serviceability of the container has not been available. The purpose of this circular is to present the results of special tests made at the Forest Products Laboratory to determine the effect of knots in certain box parts and to show how knotty lumber can be used in boxes without decreasing the serviceability of the container. Recommendations regarding the size and position of knots in the several parts of wooden boxes are given which are based not only on the tests presented but on extensive experience in tests of boxes and other wooden products and on observation of containers in service.

The results and recommendations embodied in this circular have a bearing on the utilization of low-grade lumber that is of interest not only to the box manufacturer and ultimate consumer, but to the forester and timber owner as well.

GENERAL CONSIDERATIONS

The use of knotty material in box making requires careful attention in order to produce a box of balanced construction; that is, a box that has enough strength in each part for the purpose intended and neither more nor better material in any part than is necessary. The construction of such a box involves a proper interrelation of three factors: (1) Nailing, (2) resistance of parts to cross breaking, and (3) resistance to puncture. Numerous tests and observations have shown conclusively that fastenings are usually the weakest feature of a box, and that it is seldom possible or practicable to nail a box well enough to develop the cross-breaking strength of parts that are free from knots or other defects. Consequently, lumber containing a relatively large proportion of knots, instead of clear lumber, can be used with good results, if it is well nailed.

Knots in box parts affect (1) the nailing of parts to each other, and (2) the bending strength and the puncture resistance of the part.

Good nailing practice dictates that knots must not be so located as to lessen the effectiveness of the nailing. Common experience and observation show that splitting and shattering results when nails are driven into knots in boards of the thicknesses commonly used in boxes, and that when nails are so driven the fastening is very poor, regardless of which of the pieces nailed together contains the knot. Consequently, no special tests are required to demonstrate the effect of knots on nailing.

TESTS TO DETERMINE THE EFFECT OF KNOTS IN BOX PARTS

In order to study effectively the influence of knots in box parts it was first necessary to determine their effect upon the bending strength and stiffness of boards, and then their effect upon the strength of a box packed for shipment.

In these tests, clear boards, glued together to form a box side, were compared to similar assemblies containing knots of different size, shape, character (figs. 1 and 2), occurrence (fig. 3), and location.

Knots were classified according to: Shape [2]—round, oval, or spike; character [3]—intergrown or incased; occurrence [4]—single or cluster; position in box side—near center of length or near quarter point of length; and size, expressed as the ratio of the diameter of the knot to the width of the board in which it occurs.

This classification, which is the same as given in United States Department of Agriculture Circular 296, Standard Grading Specifications for Yard Lumber,[5] makes possible closer comparisons of the various kinds of knots than the general classification used by the American lumber standards.

MEASUREMENT OF KNOTS

The diameter of a knot or knot cluster was measured by the distance between lines that are parallel to the length of the board and that touch the edge of the knot or knot cluster. (Figs. 1, 2 A, and 3.) The diameter of any one round knot, oval knot, or knot cluster, was determined by the mean of the measurements taken on both faces of the board in which it appeared. Each spike knot was measured on the worse face of a board only, since the stresses may come upon it in either direction. (Fig. 2, B.)

BENDING TESTS ON KNOTTY BOARDS

The principal conclusions, derived from static bending, impact bending, and compression parallel to the grain tests made to determine the effect of knots on the strength of second-growth northern white pine box lumber,[6] are as follows:

(1) The size of the knot or of the knot hole represents the portion of the width of the board rendered ineffective in resisting cross-breaking stress.

(2) The shock-resisting capacity of the board is reduced by a knot to a greater extent than is the resistance to cross-breaking stress.

(3) The stiffness of the board is less affected by knots than is the cross-breaking strength.

(4) The shape of the knot, that is, whether round, oval, or spike, is not an important factor in the strength of the board.

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[2] A round knot is one whose maximum diameter is not over one and one-half times as great as its minimum diameter. An oval knot is one whose maximum diameter is more than one and one-half but not more than three times its minimum diameter. A spike knot is one sawed in a lengthwise direction and whose maximum diameter is over three times its minimum diameter.

[3] An intergrown knot is one whose growth rings are completely intergrown with those of the surrounding wood. An incased knot is one whose growth rings are not intergrown and homogeneous with the growth of the surrounding wood. The incasement may be partial or complete.

[4] A single knot is one occurring by itself with the fibers of the wood in which it occurs deflected around it. A knot cluster is two or more knots grouped together as a unit with the fibers of wood deflected around the entire unit. A group of single knots is not a knot cluster.

[5] Ivory, E. P., White, D. G., and Upson, A. T. STANDARD GRADING SPECIFICATIONS FOR YARD LUMBER. U. S. Dept. Agr. Circ. 296, 75 p., illus. 1923.

[6] Acknowledgment is made to the New England Box Co. and to the New Hampshire State College for assistance in obtaining the northern white pine lumber for use in the tests, and to R. F. Luxford of the Forest Products Laboratory for conducting the tests and analyzing the test data on the effect of knots on the strength of lumber.

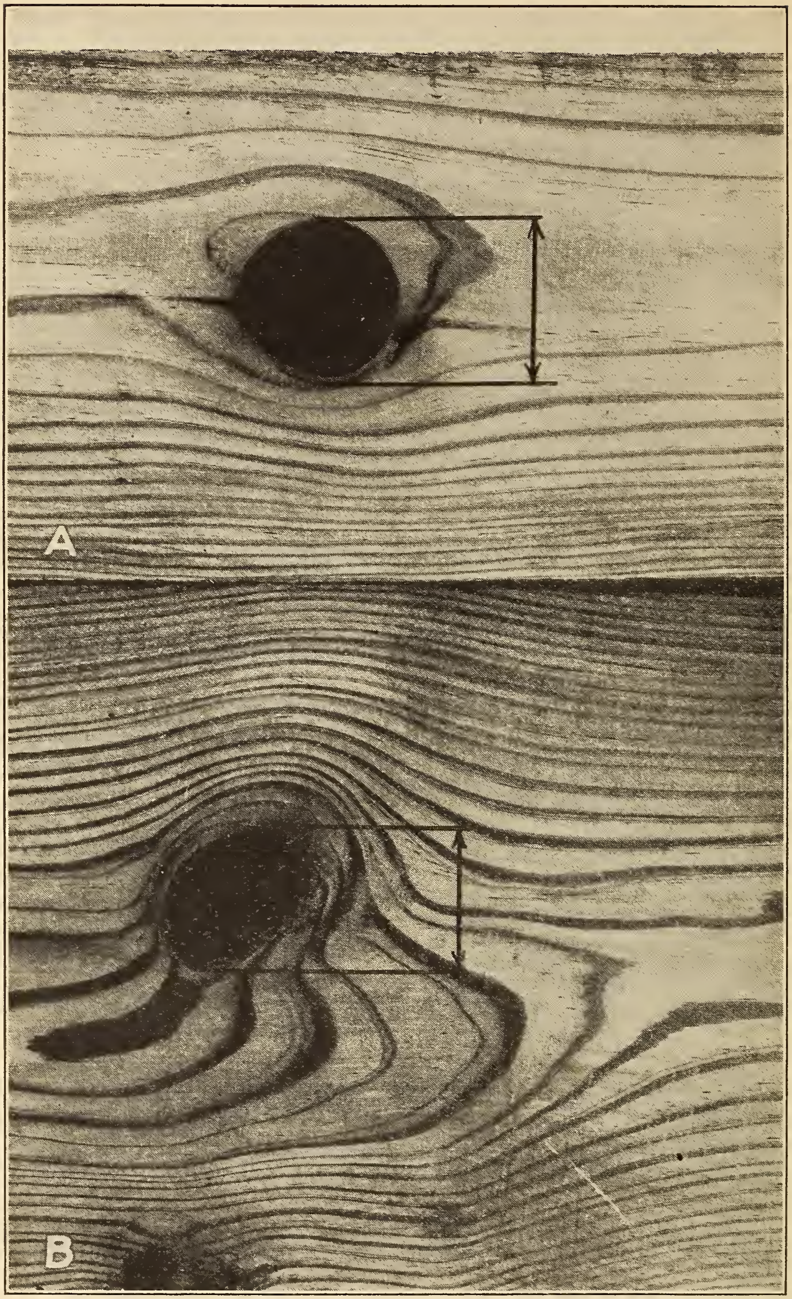

FIGURE 1.—Intergrown knots: A, Round knot; B, oval knot. Dimension lines indicate method of measurement

(5) Whether a knot is intergrown or incased is not an important factor in the strength of the board.

(6) The position of the knot is of no great importance, provided it does not occur in the nailing edge.

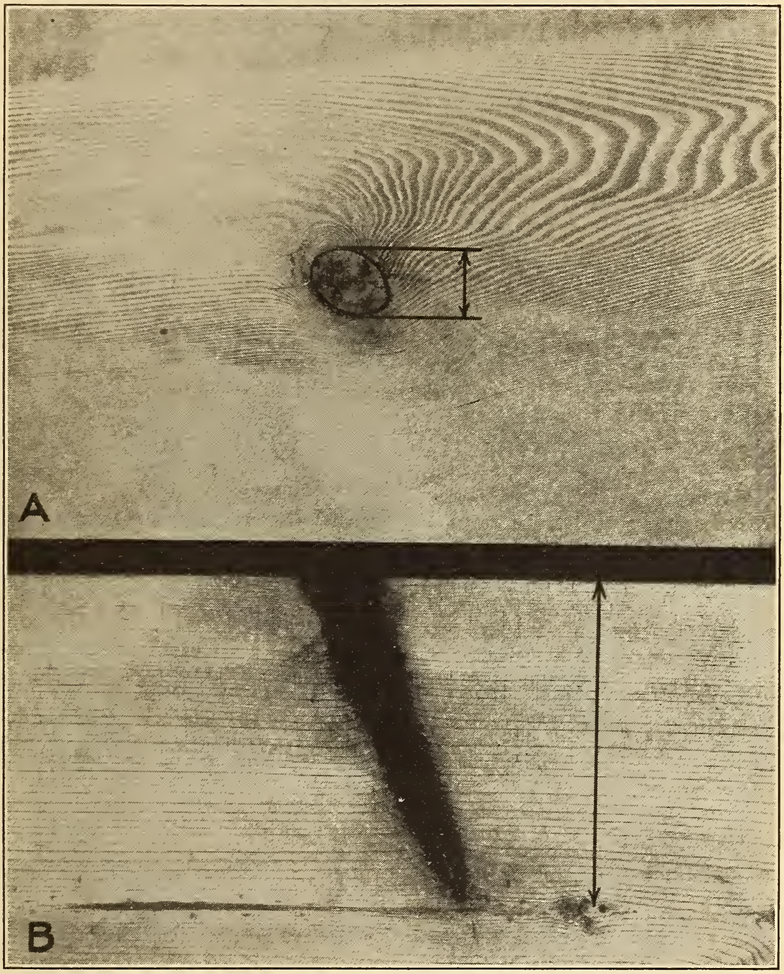

FIGURE 2.—Incased and intergrown knots: A, Incased knot; B, spike knot, intergrown for most of its length. Dimension lines indicate method of measurement

DROP TESTS ON BOXES WITH KNOTTY SIDES

Since the nailing is normally the weakest part of a box, the tendency of knots to lower the strength of box lumber will not weaken the box until knots of considerable size are present. The following drop tests on boxes with knotty sides were made to determine the size of knots allowable in boxes carrying commodities. The box styles, sizes, weights of contents, and thicknesses of lumber

FIGURE 3.—A knot cluster. Dimension lines indicate method of measurement

used in the tests were selected as being representative of commercial practice.

SPECIFICATIONS FOR BOXES TESTED

The boxes tested are designated as "A boxes" and "B boxes." The A boxes were of the style 4 nailed construction (fig. 4, A), the inside dimensions of which were 33½ by 16¾ by 13¾ inches. The B boxes were of the style 5 nailed construction (fig. 4, B), the inside dimensions of which were 17¼ by 13 by 9⅞ inches.

The A boxes had 2-piece $\frac{13}{16}$-inch ends reinforced with two $\frac{13}{16}$-inch by 2-inch cleats. The same type of end construction was used with ⅝, ½, and ⅜ inch 3-piece sides, tops, and bottoms. The cleats were nailed to the ends with 6-penny cement-coated cooler nails [7] spaced about 2 inches apart, driven through the cleats and ends,

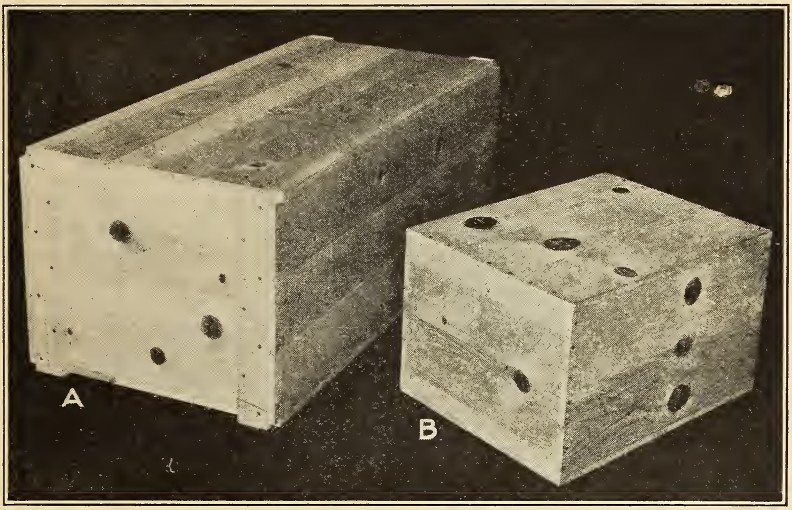

FIGURE 4.—Tongued-and-grooved joints between the individual pieces making up the box faces: A, An A box having inside dimensions of 33½ by 16¾ by 13¾ inches; B, a B box having inside dimensions of 17¼ by 13 by 9⅞ inches

and clinched on the inside. Sides, tops, and bottoms were fastened to the ends and cleats with seven 8-penny cement-coated cooler nails in each nailing edge. The nails at the ends of the sides were staggered, four being driven into the cleat and three into the box end.[8]

The B boxes had 2-piece ⅝-inch ends reinforced with two ⅜ by 1⅛ inch inside cleats in combination with $\frac{5}{16}$ or $\frac{7}{16}$ inch sides, tops, and bottoms. The tops and bottoms were of three pieces, and the sides were of either two or three pieces. The cleats were nailed to

[7] Cooler nails are identical to sinker nails except for their heads. The head of the cooler nail is flat on the under side, whereas the head of the sinker nail is cone shaped on the under side and is slightly smaller. Either can be used in a nailing machine. Standard box nails are the same length as cooler nails and sinker nails, but are smaller in diameter.

[8] The nailing used in these tests approximates very closely that of the nailing schedule recommended by the Forest Products Laboratory and accepted by the National Association of Wooden Box Manufacturers. This schedule is given in the following publication: UNITED STATES DEPARTMENT OF AGRICULTURE, FOREST SERVICE, FOREST PRODUCTS LABORATORY. THE NAILING OF BOXES. U. S. Dept. Agr., Forest Serv. Forest Prod. Lab. Tech. Note B–10. 3 p. n. d. [Mimeographed.]

the ends with 4-penny cement-coated cooler or sinker nails spaced about 1¾ inches apart, driven through the cleat and end, and clinched on the outside. The sides, tops, and bottoms, were fastened to the ends with seven 6-penny cement-coated cooler or sinker nails to each nailing edge.

All joints between the pieces making up the faces of the boxes were tongued and grooved and were glued with animal glue. (Fig. 4.)

One side of each box was made of pieces containing knots varying in diameter, shape, character, and location. The other parts of the box were made of essentially clear lumber. These boxes were tested and compared with clear boxes; namely, boxes having no knots.

CONTENTS OF BOXES

The A boxes were filled with ninety-six 1-pound cylinders and the B boxes with twenty-four 2½-pound cylinders arranged so as to produce a maximum bending stress in the sides containing the knots when given a "drop-on-edge" test.

TEST PROCEDURE

The boxes were dropped alternately on the two edges at which the sides containing the knots were fastened to the ends. They were given two drops on each of these edges, making four drops for each height of 6, 12, 18, 24, and 30 inches, or until failure occurred.

Moisture-content determinations were made on samples of lumber cut from each box immediately after the test.

RELATION BETWEEN TEST AND SERVICE CONDITIONS

The "drop-on-edge" test (fig. 5) does not bring shearing stress fully into play in the box sides nor does it permit pulling of the nails at the edge on which the box is dropped. The application of the test, therefore, resulted in more bending stress on the box sides, and, consequently, in a somewhat larger percentage of cross-breaking failures than would have occurred under the usual shipping hazards.

PRESENTATION OF DATA

The essential parts of the test data are presented in five charts, Figures 6 to 10, inclusive. The horizontal scale of the charts represents the ratio of the diameter of the knot to the width of the board in the box side, also the ratio of the aggregate projected diameter of the knots at the section under consideration to the width of the box side. The vertical scale represents the measure of the resistance of the box to rough handling. This measure, which is expressed in feet, is a summation of the heights from which each box was dropped. The curve shown in each figure is drawn approximately through the average of the summation of the heights of drop required to cause failure. Although these figures show a wide spread of points, which necessarily accompanies all box tests, they visualize the effect of knots on the serviceability of the boxes that were tested, and are presented for that purpose.

Each point on the charts, except the points for clear boxes, represents one test. The number of clear boxes represented by each point

is indicated by a numeral adjacent to the point. Shape, character, and position of the knots in the box face, and location of the failure are indicated by combinations of the following symbols:

Shape: Round—a circular symbol; oval—a triangular symbol; spike—a diamond-shaped symbol.

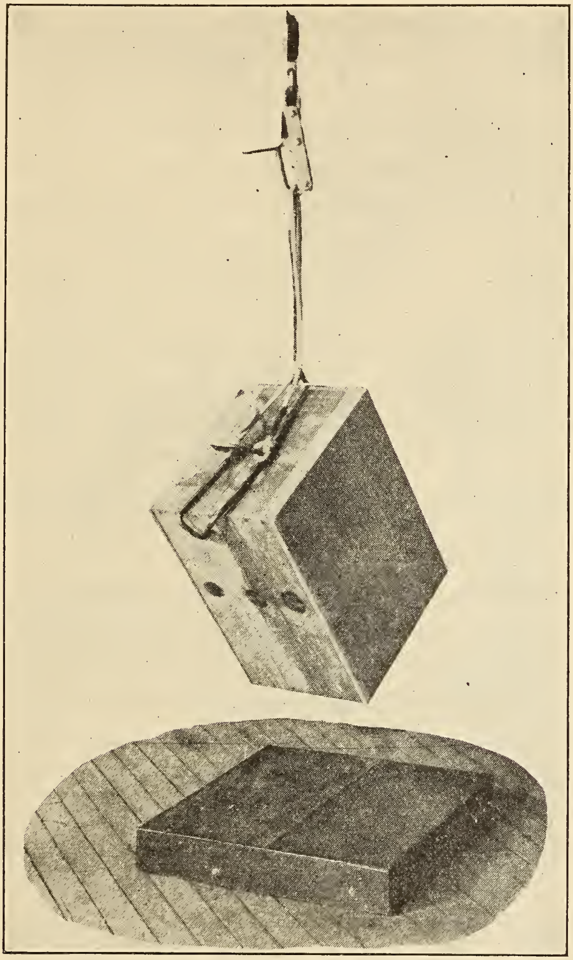

FIGURE 5.—Method of making "drop-on-edge" test

Character: Incased knots—a dash over the symbol. All others are intergrown.

Position: At quarter point of length of box side—a dot over the symbol. All others are at the center of length of the box side.

Failure: At nails—an open symbol; at knots—a solid black symbol.

DISCUSSION

Before discussing in detail the influence of knots in box lumber on the strength of boxes, it is well to consider some of the charac-

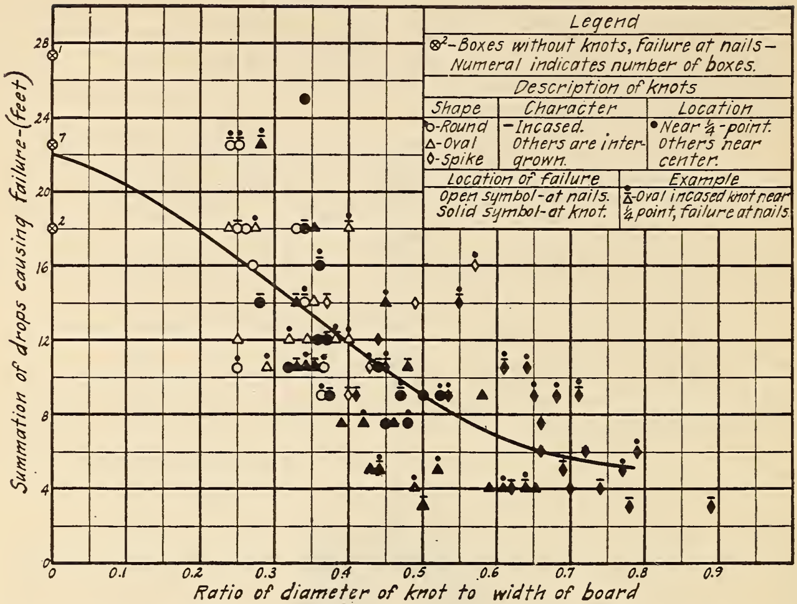

FIGURE 6.—Effect of character, shape, and location of knots on the strength and serviceability of the A boxes with ⅜-inch sides, tops, and bottoms. Inside dimensions 33½ by 16¾ by 13¾ inches

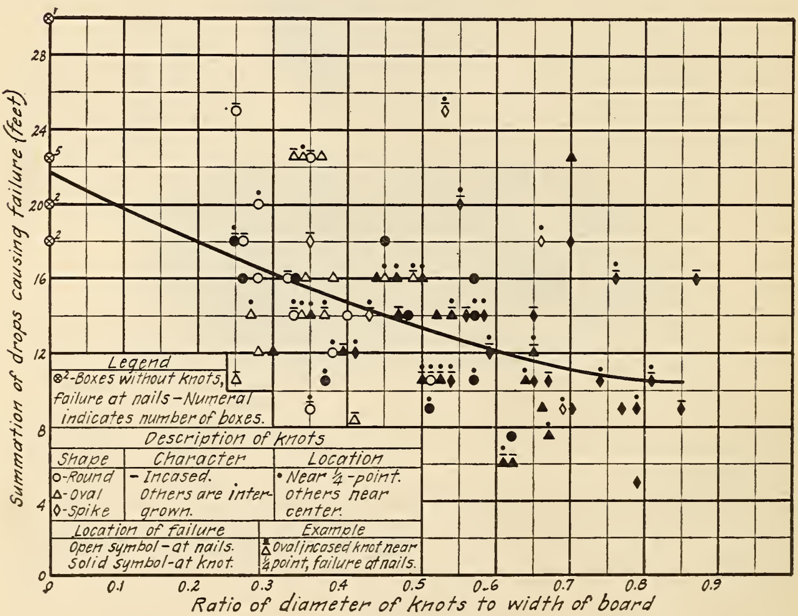

FIGURE 7.—Effect of character, shape, and location of knots in the sides of the A boxes with ½-inch sides, tops, and bottoms. Inside dimensions 33½ by 16¾ by 13¾ inches

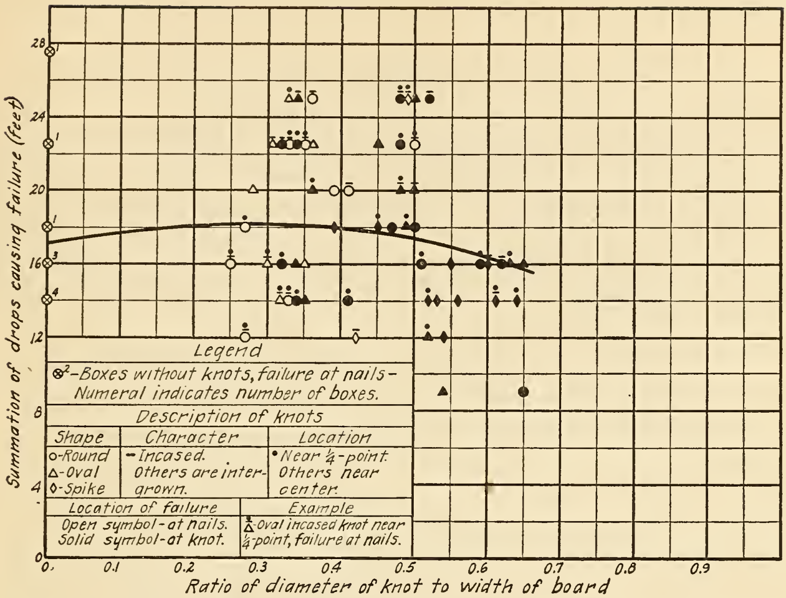

FIGURE 8.—Effect of character, shape, and location of knots on the strength and serviceability of the A boxes with ⅝-inch sides, tops, and bottoms. Inside dimensions 33½ by 16¾ by 13¾ inches

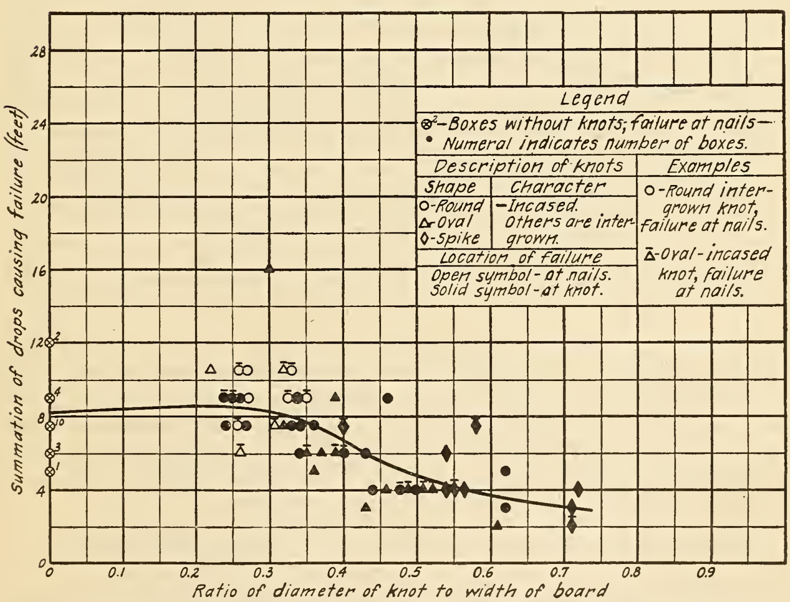

FIGURE 9.—Effect of character and shape of knots on the strength and serviceability of the B boxes with $\frac{5}{16}$-inch sides, tops, and bottoms. Inside dimensions 17¼ by 13 by 9⅞ inches

teristics of clear box lumber in relation to nailing and to balanced construction.

BENDING STRENGTH AND STIFFNESS OF CLEAR LUMBER AS RELATED TO NAILING

Boxes that are constructed of clear straight-grained lumber seldom fail by the boards breaking across the grain. The common failures are the result of one or more of the following causes: The nails pulling out of the box ends; shearing out the wood at the nails in the ends of the sides, tops, and bottoms; the nail heads pulling through the boards; the boards splitting; or the nails breaking off. Obviously, in all such failures, the effect of size, number, and spacing of nails is important.

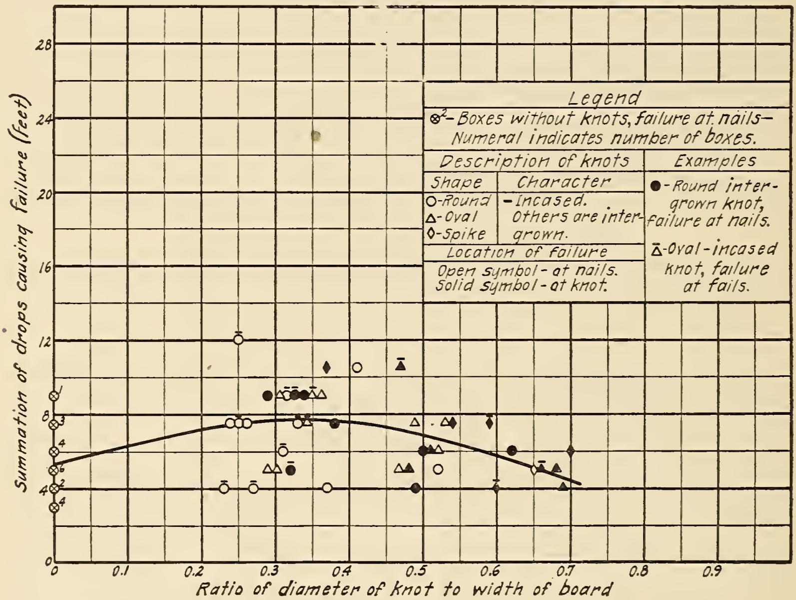

FIGURE 10.—Effect of character and shape of knots on the strength and serviceability of B boxes with $\frac{7}{16}$-inch sides, tops, and bottoms. Inside dimensions $17\frac{1}{4}$ by 13 by $9\frac{7}{8}$ inches

Tests and experience demonstrate that the nailing used in these tests approximates very closely the maximum number of nails that can satisfactorily be used. Any increase beyond this nailing will often require more staggering of the nails and an increased thickness of the box ends to avoid splitting of the box ends at the nails. Moreover, additional nails in many instances would require an increased number of nailing-machine operations.

RELATION OF SLENDERNESS RATIO TO BALANCED CONSTRUCTION

The ratio of the length of a box board to its thickness is defined as its slenderness ratio. This term is used in classifying box boards as thick or thin. From the nature of the failures of boxes made of

clear lumber, it has been deduced that clear box boards having a slenderness ratio greater than about 60 may be considered thin, and less than 60 thick.

If the boards are thin a large part of the shocks during transportation are absorbed by springing and bending of the boards. The tendency to pull the nails is not great, but the movement of the boards works them loose from the nails. If such boxes are nailed in accordance with the nailing used in these tests, the failures are likely to be by shearing out the wood at the ends of the boards or by pulling the nail heads through.

If the boards in the sides, tops, and bottoms of boxes are thick, the shocks incident to rough handling are transmitted as a direct pull on the nails by the contents of the box. For such boxes, when nailed in accordance with the nailing used in these tests, the failures are by the nails pulling out of the ends.

If the boards have a slenderness ratio of about 60, and the nailing is about as provided in the present tests, the failures are usually divided between shearing and pulling the nail heads through, and pulled nails.

TYPES OF FAILURES IN TESTS OF BOXES MADE OF CLEAR LUMBER

The A boxes with ⅜-inch clear sides, tops, and bottoms (thin) were approximately equal in strength to the A boxes with ½-inch clear sides, tops, and bottoms (thin). The ⅜-inch boards were so flexible that they worked loose from the nails, the box failures generally being by shearing from nails. The deeper penetration of the nails in the ends with the ⅜-inch material had no beneficial effect since the failures were not by the nails pulling. The ½-inch material also worked loose from the nails, as a rule, but some of the nails were pulled. The A boxes with ⅝-inch clear sides, tops, and bottoms (thick) failed with less rough handling than the ½ and ⅜ inch boxes because the greater stiffness of the sides and the lower penetration of the nails combined to result in box failures by direct pull of the nails. The B boxes with $\frac{5}{16}$ and $\frac{7}{16}$ inch clear sides, tops, and bottoms (thick) also failed by direct pull of the nails, largely because of the excess stiffness of the sides, the $\frac{7}{16}$-inch material giving poorer results than the $\frac{5}{16}$-inch material.

Slenderness ratios of the various box boards used are shown in Table 1.

TABLE 1.—*Thickness of sides, slenderness ratios, and classification of the box boards used in tests*

Box	Thickness of sides	Slenderness ratio	Classification	Box	Thickness of sides	Slenderness ratio	Classification
	Inch				*Inch*		
A	⅜	$\frac{33\frac{1}{2}}{\frac{3}{8}}=89$	Thin.	B	$\frac{5}{16}$	$\frac{17\frac{1}{4}}{\frac{5}{16}}=55$	Thick.
A	½	$\frac{33\frac{1}{2}}{\frac{1}{2}}=67$	Do.	B	$\frac{7}{16}$	$\frac{17\frac{1}{4}}{\frac{7}{16}}=39$	Do.
A	⅝	$\frac{33\frac{1}{2}}{\frac{5}{8}}=54$	Thick.				

It would usually require 50 per cent more nails than are ordinarily used[9] to cause boxes with clear sides, tops, and bottoms of the customary minimum thicknesses[10] to fail by the boards breaking across grain instead of shearing from the nails. Increasing the thickness of sides, tops, and bottoms without changing the nailing also provides greater shearing resistance. Clear lumber of the thickness necessary for proper shearing strength at the nails, however, has cross-breaking strength in excess of that required for balanced construction.

INFLUENCE OF KNOTS ON CROSS-BREAKING STRENGTH AND STIFFNESS

Knots reduce the cross-breaking strength of a board. However, if the sides, tops, and bottoms of boxes are of sufficient thickness to resist shearing at the nails, knotty boards may be used without causing cross-breaking failures. The degree of knottiness required to fulfill the above conditions is clearly indicated by the results of the tests. (Figs. 11 and 12.)

The A boxes with $\frac{3}{8}$-inch (fig. 6) and $\frac{1}{2}$-inch (fig. 7) sides, tops, and bottoms show a decrease in strength with increase in knot diameter even where the knots were too small to cause failure by cross breaking, while the A boxes with $\frac{5}{8}$-inch sides, tops, and bottoms (fig. 8) and the B boxes with $\frac{5}{16}$ and $\frac{7}{16}$ inch sides, tops, and bottoms (figs. 9 and 10) show a slightly higher strength with increase in knot diameter up to about one-third the width of the board. The explanation is that the reduction in stiffness due to knots increased the tendency of the thin boards (those with slenderness ratios greater than 60) to work loose from the nails, whereas the reduction in stiffness of the thick boards (those with slenderness ratios less than 60) relieved the stresses tending to pull the nails. Increasing the knot size in a board is thus seen to have the same general effect as increasing the slenderness ratio of a clear board in so far as the nail failures are concerned.

BALANCE BETWEEN KNOT FAILURES AND NAIL FAILURES

If the knots are large enough the cross-breaking strength of the box board is reduced below the strength of the nailing. (Fig. 13.) Failures by breaking across grain then predominate and the amount of rough handling the box will withstand is less, on the average, than if the full strength of the nailing is utilized. Ordinarily, it is preferable to have nail failures in a box rather than to have the box boards break across grain. Knots large enough to consistently cause cross-breaking failures should, therefore, be avoided.

With knot diameters of about one-fourth the width of the boards there were very few failures as a result of the boards cross breaking at the knots in either the A or B boxes.

With knot diameters of one-third the width of the boards, more than one-half of the A boxes with $\frac{3}{8}$-inch (thin) sides, tops, and bottoms failed by cross breaking at the knots, and in the A boxes with $\frac{1}{2}$-inch (thin) sides, tops, and bottoms failures at the nails

[9] The Forest Products Laboratory nailing schedule is ordinarily used. (See footnote 8.)

[10] NEWLIN, J. A., and PLASKETT, C. A. REPORT OF COMMITTEE D–10 ON SHIPPING CONTAINERS. Amer. Soc. Testing Materials Proc. (27th Ann. Meeting) 24 (Pt. 1): 663. 1924.

predominated. The ½-inch boxes that failed by cross breaking at the knots, however, averaged considerably lower in the number of drops received in the tests than the boxes failing at the nails. The slenderness ratio of the ⅜-inch boards was 89 (thin), and of the

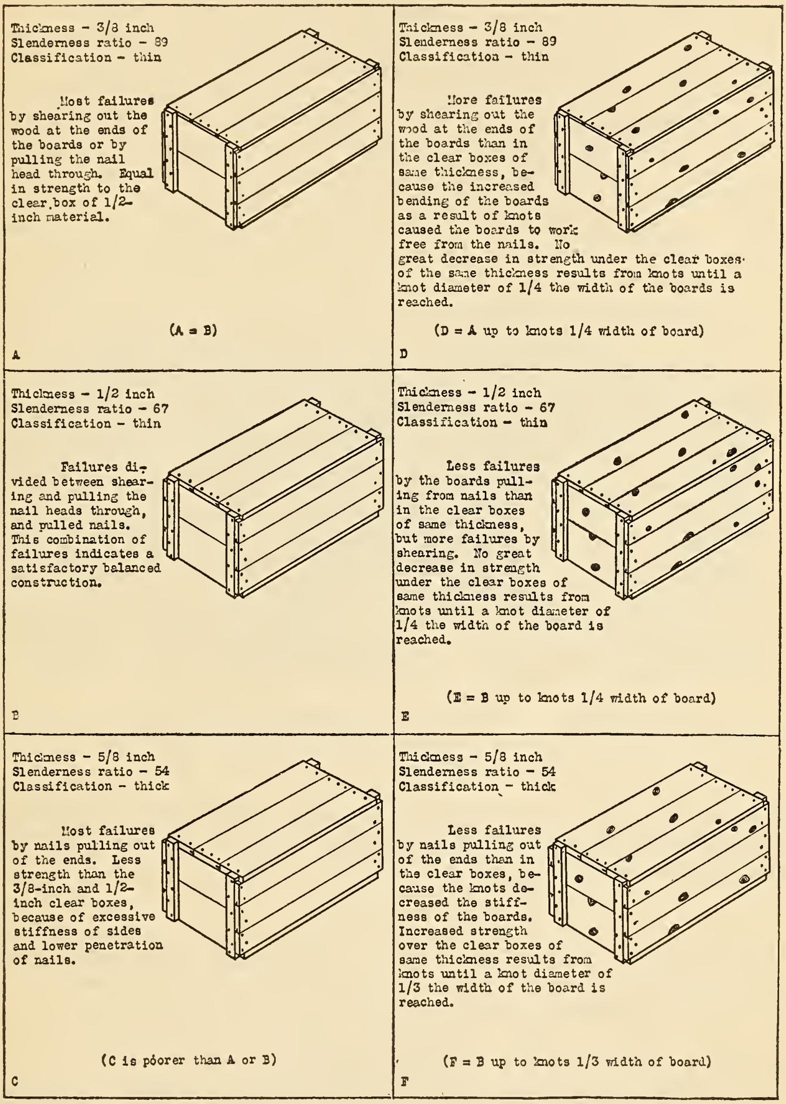

Figure 11.—Comparison of clear and knotty A boxes

½-inch boards 67 (thin). Because of the large percentage of failures by cross breaking at the knots in the ⅜-inch boards and because of the large reduction in resistance to rough handling with both ⅜ and ½ inch material when the larger knots were present, it ap-

pears advisable to limit knot diameters to about one-fourth the width of boards that have slenderness ratios greater than 60.

The A boxes with ⅝-inch (thick) sides, tops, and bottoms, and the B boxes with $\frac{5}{16}$ and $\frac{7}{16}$ inch (thick) sides, tops, and bottoms, and having knot diameters of about one-third the width of the boards, withstood as much rough handling as boxes with the same thickness of clear boards, although, when tested to destruction, a considerable number failed by cross breaking at the knots. The fact that the amount of rough handling was not reduced indicated that practically the full strength of the nailing was utilized. It is therefore concluded that with slenderness ratios of less than 60 the diameters of any one knot may be as great as one-third the width of a board without decreasing the strength of the box.

The B boxes with $\frac{7}{16}$-inch short, thick sides, tops, and bottoms deserve special mention. The number of drops received in the tests to cause failure of these boxes averaged 50 per cent higher for knot sizes of one-third than for clear material. The slenderness ratios of the boards in these boxes was 39 (thick), the lowest of any

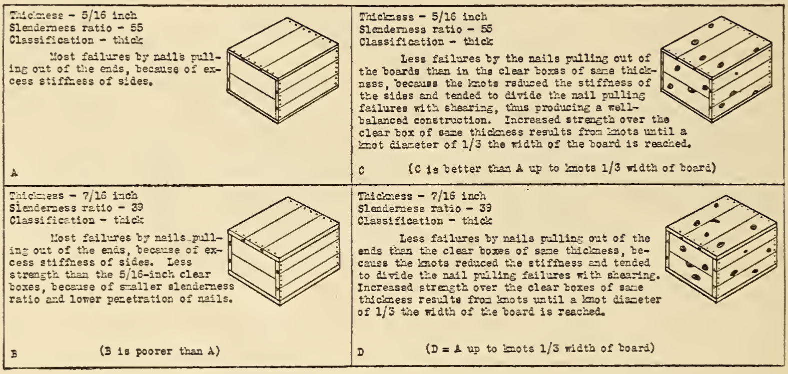

FIGURE 12.—Comparison of clear and knotty B boxes

of the boxes tested. This clearly indicates that knotty lumber will make a box with short, thick sides more resistant to rough handling than if it were made of clear lumber.

SHAPE OF KNOT

The box tests show that knots of equal size, when measured as recommended in this circular, have equal influence on the strength of the box regardless of the shape of the knots; that is, whether they are round, oval, or spike. This may readily be seen by reference to Figures 6–10, where the symbols representing each shape of knot are found to be generally about equally divided above and below the curve representing the average summation of drops necessary to cause failure.

CHARACTER OF KNOT

The test results show little difference in the relative effect of intergrown and incased knots or of knot holes on the strength of boxes. (Figs. 6–10.) The fact that an incased knot is loose and often

drops out, however, may be objectionable on account of the resulting exposure of the commodity or the loss of the bulk contents of the box.

OCCURRENCE AND LOCATION OF KNOT

In addition to the effect of the size, shape, and character of a knot on the strength and serviceability of a box, there is the effect of the occurrence and location of the knot in the box face. As already mentioned, knots should be excluded from the nailing edge. (Fig. 14.) Knot clusters whose widths are greater than the permissible diameter of a single knot, and other combinations of single knots that would be more injurious in effect than the maximum single knot allowable, should be excluded from all box boards. Knots whose aggregate diameters within a length equal to the width of the board are less than that of the maximum allowable knot, usually do not combine to cause failure.

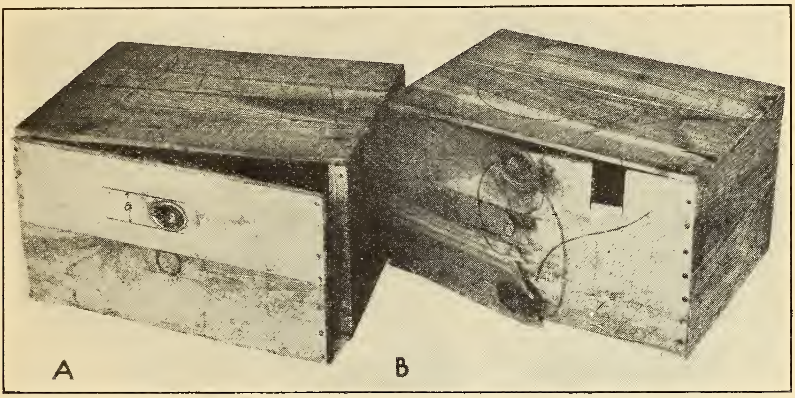

FIGURE 13.—Size of knots determines the type of failure: A.—Knots less than one-third the width of the board. Failure at nails. *a*, Method of measuring the diameter of a knot. B.—Knots more than one-third the width of the boards. Failure at knots. The rectangular cut shows where moisture-content sample was removed

Beyond the limits just stated, the location of a knot in the sides, tops, and bottoms of boxes has little effect upon cross breaking. (Figs. 6–10.) Cross-bending tests with one-third point loading on thin lumber show slightly less influence with knots at the one-fourth point than at the center of a box side. However, the various transportation hazards which are encountered by a box and the large range of box sizes found in service tend to obscure this difference.

METAL BINDINGS MODIFY THE INFLUENCE OF KNOTS

NAILED STRAPPING

Metal straps when used to reinforce a box modify the effect of knots on the strength and serviceability. If nailed strap binding is placed around a box at the ends, both the strap and the additional nails used in attaching it reinforce the box against failure at the nails, thus permitting the use of relatively thin boards in all parts except the ends. The boards, however, must have sufficient cross-bending

strength to retain the balanced construction in the box and should therefore contain only very small knots. Boards containing knots approximately 25 per cent smaller in size than permitted in unstrapped boxes should be used in boxes that are reinforced with nailed straps placed near the box ends.

NAILLESS STRAPPING

Nailless binding, either of the round-wire or of the flat-strap type, is normally placed some distance from the ends of the box. Such

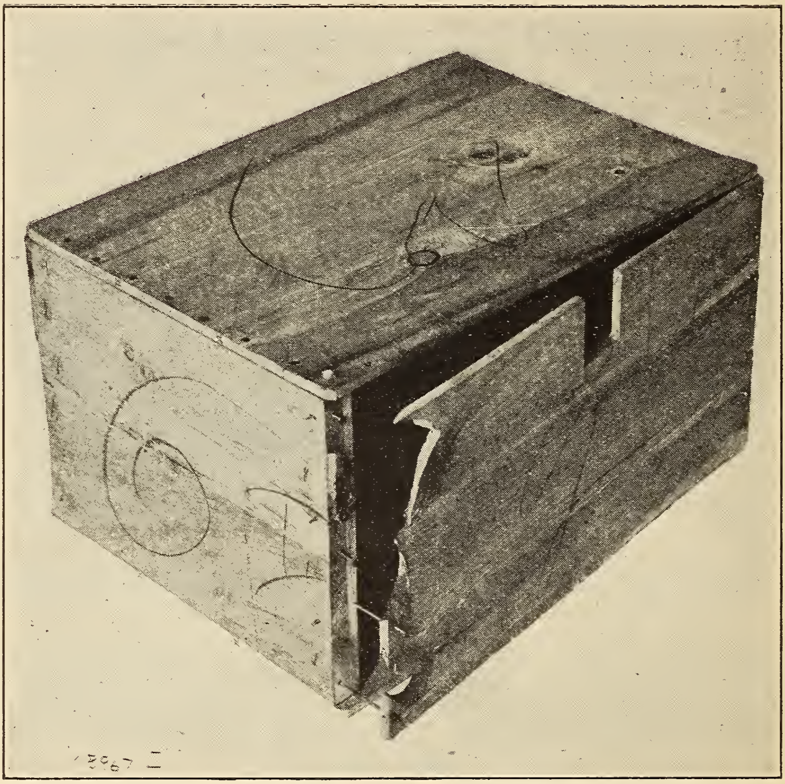

FIGURE 14.—Knots in the nailing edge prevent efficient nailing and lower the strength of boxes. The sample used for the determination of the moisture content of the box material was taken from the rectangular cut shown on the box face

binding helps to counteract nail pulling and cross breaking. Therefore boards containing knots as large as those used in unstrapped boxes (p. 19) are allowable in boxes with nailless binding, since the total strength of the box is increased without the loss of a reasonable balance in construction. The net result is a stronger box than an unstrapped box for the same thickness of lumber, or a box of the same strength but made of a somewhat thinner lumber of the same degree of knottiness.

INFLUENCE OF PUNCTURE RESISTANCE ON PERMISSIBLE SIZE OF KNOT

Protection of certain commodities against puncture of the box may sometimes justify an increase in thickness of box sides, tops, and bottoms beyond that called for in balanced design. Such increase in thickness will permit the use of lumber with slightly larger knots than are normally allowed. The diameter of the knot, however, should not exceed one-half the width of the board in which it occurs in box sides, tops, and bottoms of slenderness ratios under 60 (thick) or one-third the width of each board of slenderness ratios over 60 (thin).

RECOMMENDATIONS

The indiscriminate use of knotty stock may produce inferior boxes, but the elimination of all knots is unnecessary, because knots up to

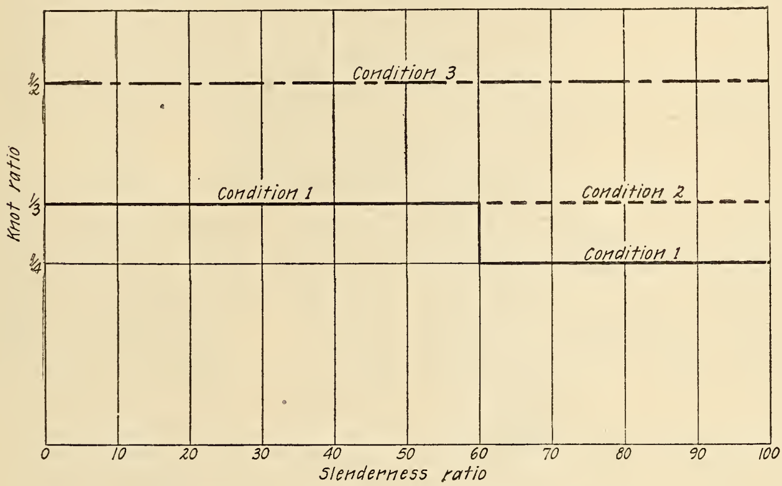

FIGURE 15.—Knot ratios permitted in box boards having various slenderness ratios, when used in unstrapped boxes or in boxes bound with nailless straps. (For boxes bound with nailed straps, knots only three-fourths as large are permitted.) Condition 1—When the thicknesses required to obtain adequate nailing have been determined by experience, test, or computation. Condition 2—When the slenderness ratio is greater than 60, but thickness is increased 5 per cent over condition 1. Condition 3—When the thickness is increased 15 per cent over condition 1

the sizes recommended below, which are also given in Figure 15, make as serviceable a box as can be made from clear stock.

UNSTRAPPED BOXES

When the thicknesses required to obtain adequate nailing have been determined by experience, test, or computation, the sides, top, and bottom of an unstrapped box may contain knots, knot holes, or knot clusters provided the diameter of any one knot, knot hole, or knot cluster (measured as described on p. 3), or the sum of the diameters of all knots within a length equal to the width of the board does not exceed—(1) One-fourth of the width of a board in a box made of thin boards (slenderness ratio greater than 60); (2) one-third of the width of a board in a box made of thick boards (slenderness ratio less than 60); (3) one-third the width of a board in a box

made of thin boards (slenderness ratio greater than 60), provided the thickness of the boards is increased approximately 5 per cent; or (4) one-half the width of a board in a box of any size, provided the thickness of the boards is increased at least 15 per cent.

BOXES WITH NAILED STRAPPING

The size of any knot in a side, top, or bottom board of a box reinforced with nailed straps placed near the box ends may be approximately three-quarters as large as that permitted for an unstrapped box.

BOXES WITH NAILLESS STRAPPING

The size of any knot in a side, top, or bottom board of a box reinforced in the usual manner with nailless straps may be as large as in an unstrapped box regardless of whether advantage is taken of the reduction in thickness permitted when strapping is used.

ALL BOXES

No knot that will interfere with the nailing of a box should be permitted in any box part.

SIDES, TOPS, AND BOTTOMS

Every piece in the sides, top, or bottom containing a knot cluster whose width is greater than the permissible width of a single knot should be excluded.

Every piece in the sides, top, or bottom containing knots whose aggregate diameters within a length equal to the width of the board exceeds the diameter of the largest knot allowable should be excluded.

ENDS

Since the ends are ordinarily thicker and shorter than the sides, top, and bottom, the size of a knot permitted in the ends may be one-half the width of the piece in which it occurs provided the knot does not interfere with nailing.

CLEATS

All box cleats should be practically free from both knots and cross grain.

GENERAL

In addition to the foregoing recommendations the tests justify the following conclusions:

Boards with incased knots or with knot holes make as strong a box as boards with intergrown knots of the same size.

Provided that the knot is measured as recommended in this circular and that the foregoing recommendations are applied, no attention need be paid to its shape.

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